DEVELOPMENT OF ENGINEERED BAMBOO USING A LOW TECH METHOD

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ABSTRACT

Bamboo is one of the fastest growing plants and has mechanical properties similar to softwood timber. Bamboo has been commonly used for many years as a traditional construction material for low rise houses, foot bridges, roofs and construction platforms, especially in Asia and Latin America. The main reasons for the popularity of bamboo in construction can be attributed to its low cost, general availability locally and adequacy of simple, local tools and skills for fabrication.

Application of bamboo in construction is, however, normally limited to low cost housing and temporary structures due to a number of factors including irregular shapes, hollow circular cross-sections and durability issues. This paper presents the results of an investigation into production of an engineered bamboo product using a low tech method. Bamboo culms were cut into smaller strips and were re-constituted into rectangular beam sections by gluing. Such a process overcomes the presence of the inherent hollow core and randomises the inter-nodes and other growth characteristics found in natural bamboo – in much the same way that engineered wood products such as plywood and LVL are produced. Flexural properties of the manufactured engineered bamboo were then compared with natural bamboo. Higher flexural strength and stiffness and lower variation in these properties, compared to natural bamboo, were achieved by re-constituting the bamboo into a manufactured product.

KEYWORDS

Bamboo, reconstitute, flexural properties.

INTRODUCTION

Bamboo has been commonly used for many years as a traditional construction material for low rise houses, foot bridges, roofs and construction platforms, especially in Asia and Latin America (Chung and Yu 2002). Low cost, local availability and adequacy of relatively simple tools and skills for fabrication are some of reasons for popularity of bamboo in construction in these regions. In Australia, application of bamboo has been limited to architectural and decorative uses only.

Tested mechanical properties of bamboo have been found to be comparable to sawn timber but bamboo possesses a number of features such as an irregular and hollow cross-section and the presence of nodes, which create variability and make it difficult to use bamboo as a construction material. A number of studies have also highlighted durability issues associated with bamboo when used in its natural form (Lakkad and Patel 1980). Low resistance against fungal and insect attack, rapid absorption of water and susceptibility of starch present in bamboo to insect have also been reported (Liese 1987).

Bamboo, however, also possesses number of unique properties which make it attractive for use as a construction material. Unlike most hardwoods, which take 50-60 years to fully mature, bamboo only takes between 3 to 6 years to fully mature; with daily growth rates of up to 100 cm having been reported (Chung and Yu 2002, Liese 1987). Bamboo grows naturally in all continents except Europe. Some bamboo species can tolerate temperatures in excess of 40 degrees, whist other species can withstand prolonged frost (Liese 1987). The carbon sequestration rate for bamboo is similar to that of a hardwood forest and the material can therefore act as a carbon sink (Janssen 2000, Nath et al 2009). Furthermore, bamboo does not require pesticides and needs only limited amount of fertilizers for growth. As such, the environmental benefits of using bamboo in construction are similar to that of wood. Mechanical properties of bamboo are comparable to timber. Lakkad and Patel (1980) reported that the strength to weight ratio of bamboo was similar to that of steel and glass reinforced plastic based on their experimental investigation and Nath et al. (2009) reported an oven-dried density between 500-800 kg/m^3 for bamboo, which is very much similar to most softwood species. Also, metabolic processes in bamboo do not produce organic and inorganic by-products such as polyphenols, resins and waxes, which can lead to favourable shrinkage, durability and gluability properties (Liese 1992).

It is evident that bamboo has the potential for uses similar to timber in construction by improving some of its undesirable properties. A number of studies have investigated this potential. Nugroho and Ando (2000 and 2001) studied the feasibility of using hot-pressed bamboo mat for manufacturing laminated bamboo lumber and found that the modulus of rupture and modulus of elasticity were comparable to laminated veneer lumber products, whilst Ahmad and Kamke (2003) report improved durability of parallel strand lumber (PSL) manufactured from Calcutta bamboo against accelerated aging. Laminated bamboo lumber with properties comparable to laminated wood products have been reported by Mahdavi et al. (2011) while the effect of type and amount of adhesive on mechanical properties glue laminated guadua (GLG) has been reported by Correal et al. (2010).

This paper presents an experimental investigation into the development of an engineered bamboo product through a low tech and simple method. Small beam specimens with rectangular cross-sections were produced by reconstituting strips of bamboo together using an adhesive. Two types of adhesives, which varied in cost, were investigated. Reconstituting the bamboo not only overcomes the presence of hollow core in natural bamboo but also randomises the inter-nodes and other growth characteristics found in natural bamboo.

SELECTION OF BAMBOO

Seven different Australian grown bamboo species were investigated and their mechanical properties were tested. Details of the investigation are reported in Cai (2012). The investigated species included (1) Bambusa Oldhamii, (2) Bambusa Tuldoides, (3) Dendrocalamus Asper, (4) Dendrocalamus Calostachys, (5) Dendrocalamus Latiflorus, (6) Gigantochloa Apus, and (7) Guadua angustifolia. Out of the seven species, Dendrocalamus Asper (referred to as Asper, here onwards) was chosen for fabrication of engineered bamboo samples. Asper species was found to have superior mechanical properties over the other species and could be splitted easily with simple tools. The culm walls of Asper was also found to be relatively thinner compared to other species, resulting in lower wastage.

FABRICATION PROCESS

The engineered bamboo specimens were fabricated by first cutting the bamboo into thin strips and then reconstituting the strips into beams with rectangular cross-section using adhesive. The fabrication process can be explained in following steps -

(i) Bamboo culm was first cut into small strips and the inner and outer layers were then removed to achieve rectangular shaped strips (Figure 1a). The strips were 10-12 mm wide and 5-10 mm thick.

(ii) The surfaces of these strips were coated with a layer of adhesive and were then laid out in a plywood formwork (Figure 1b). Two types of adhesives, Purbond® HB S109 (referred to as Purbond, here onwards), which is a one part polyurethane adhesive and polyvinyl acetate (referred to as PVA, here onwards), were used for gluing the bamboo. A thin plastic layer was laid on the formwork prior to placement of the bamboo to prevent the glue from bonding with the formwork.

(iii) Pressure was then applied to the formwork from the all sides using hand tightened G-clamps.

(iv) Specimens were left to cure for a day, after which the formwork was removed. The manufactured bamboo had a dimension of 1600x40x40mm (Figure 1c) but larger specimens can be fabricated using a similar process.

(a) (b) (c)

Figure 1: Fabrication – (a) cutting into strips, (b) layout on formwork, and (c) fabricated specimens

EXPERIMENTAL INVESTIGATION

Four-point bending tests were undertaken to investigate the flexural properties of the fabricated engineered bamboo. Two sets of specimens were tested – (i) rectangular bamboo strips reconstituted with Purbond adhesive (specimens A1-C to A5-C) and (ii) rectangular bamboo strips reconstituted with PVA adhesive (specimens P1-C to P5-C). The specimens were tested 1-2 weeks after the fabrication and were stored in normal lab conditions prior to testing. Moisture content of the tested samples was measured for each set of the specimens following the four-point bending test, using the oven-dried method in accordance with AS/NZS1080.1 (1997).

Specimen Size

The size of each of the specimens was approximately 800x40x40 mm and the sizes were measured for each specimen prior to the tests.

Test Procedure

All specimens were tested under four-point bending loading in accordance withAS/NZS 4063.1 (2010). Loads were applied at the middle one-third spans and mid-span deflection was measured with a linear variable displacement transducer (LVDT) (Figure 2 and 3). The loading rate was adjusted to 3-4 mm per minute such that the peak load was reached in about 5 minutes. Applied loads and deflection results were recorded electronically through a data-taker at the rate of 1 sample per second.

Figure 2: Four-point bending test setup for manufactured bamboo

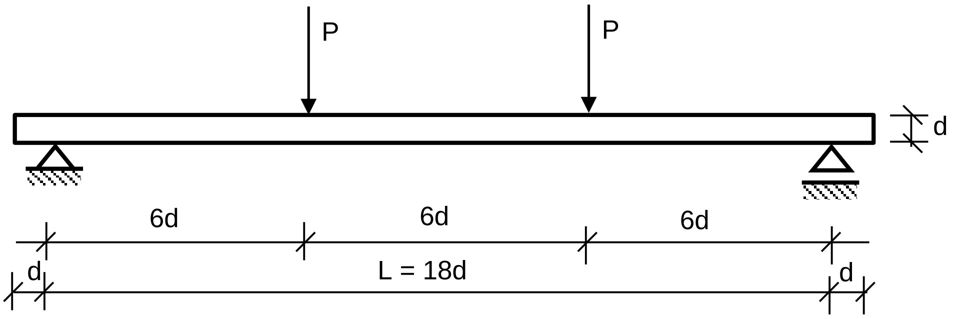


Figure 3: Schematic diagram of the four-point bending test setup

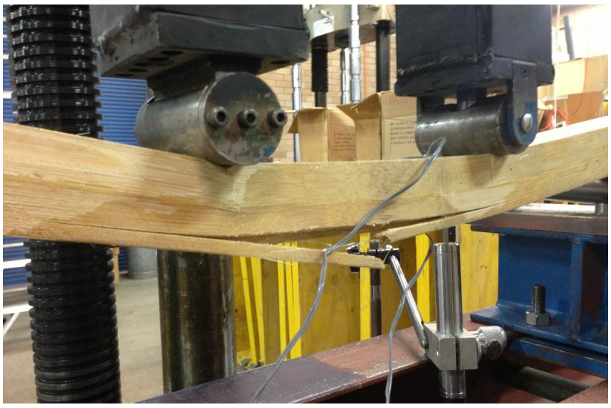
RESULTS AND DISCUSSIONS

All specimens, irrespective of the type of adhesive used, generally failed by horizontal shear splitting which initiated close to one of the supports and near the centre of the cross-section. Closer inspection of the specimen following the tests showed that the splitting occurred at or close to the adhesive layer (Figure 4a). The shear splitting was generally followed by tensile rupture of the bamboo strips at the soffit of the specimens (Figure 4b). The primary failure mode by shear splitting is attributed to the fabrication technique where the bamboo strips were laid out in layers in the form work.

It was noted that the plastic sheet used to prevent bamboo from adhering to the form work had been trapped between the bamboo strips in specimen A5-C, resulting in poor bond between the strips and hence the specimen failed at relatively lower load. Results for specimen A5-C has been discounted in all statistical analysis. This observation, however, also highlights the need for quality control during the fabrication process.

The modulus of rupture (MoR, f_b) and modulus of elasticity (MoE, E) for tested samples were calculated using on equations (1) and (2) and the results are summarised in Table 1. The strength of the tested specimens was limited by the observed failure mode. However, the variation in the strength and stiffness of the tested specimens were found be much less than that observed for natural bamboo tested under similar load setup (Table 2). This observation is of significance, as a smaller variation in the properties of the manufactured engineered bamboo means that there is inherently higher reliability in these properties which can lead to improved confidence for designers.

(a)



(b)

Figure 4: Typical failure modes (a) shear splitting and (b) tensile splitting

Whilst the variation in the properties of the manufactured engineered bamboo was lower than that for the natural bamboo, the variation is much higher than that for common engineered wood products such as laminated veneer lumber (LVL) and glue laminated timber (glulam). However, the results show that the reliability of bamboo can be significantly improved by reconstituting the bamboo using a simple and low tech method and without the need for significant capital investment.

Specimens fabricated with Purbond adhesive had relatively higher strength and stiffness compared to specimens with PVA adhesive and also the results were more consistent. Such observation is likely due to the difference in the setting behaviour of the two adhesives. Whilst Purbond expands when it sets and therefore fills up any small gaps between the bamboo strips, such properties are not found in PVA adhesive. However, it should also be noted that Purbond adhesive costs at least two times more than PVA adhesive and there are differences in the effects of moisture on the two adhesive. As such, the choice of adhesive will depend upon both the cost and nature of application.

$$f_b = \frac{P_u \frac{L}{3}}{\frac{bd^2}{6}} \tag{1}$$

Where, P_u is the ultimate load, L is the clear span between supports, b is the width and d is the depth of the tested sample.

$$E = \frac{23}{648} \times \frac{P_2 - P_1}{\Delta_2 - \Delta_1} \times \frac{L^3}{\frac{bd^3}{12}} \tag{2}$$

Where, P_1 and P_2 and Δ_1 and Δ_2 are the loads and corresponding deflection in the linear range of the load-deflection plot (normally taken at 10% and 40% of ultimate load), respectively.

Mean moisture content of the tested samples was found to be 10% and 12% for Purbond and PVA samples, respectively. The moisture content was calculated using the oven-dried method (AS/NZS1080.1 1997) and by using three 40x40x40 mm samples taken from the failed specimens for each set of samples.

Table 1 Summary of test results for engineered bamboo

Adhesive Type	Specimen	MoR MPa	MoE GPa
Purbond	A1-C	66.7	14.5
	A2-C	89.4	13.7
	A3-C	85.6	14.0
	A4-C	68.0	14.8
	A5-C	46.7	13.2
	Mean	77.4	14.2
	CoV	15%	3%
PVA	P1-C	52.3	9.9
	P2-C	88.2	16.5
	P3-C	77.7	11.0
	P4-C	79.9	12.2
	P5-C	45.9	8.1
	Mean	68.8	11.5
	CoV	27%	28%

CONCLUSIONS

This paper has presented an investigation on using a low cost and low tech method for reconstituting bamboo into an engineered product. The results have demonstrated that by reconstituting bamboo with adhesives, it is possible to overcome short comings in the properties of natural bamboo which make it difficult to put into engineered application such as high variability in properties and undesirable shape. The study demonstrates the potential of using bamboo as an engineered product by using a relative simple fabrication technique. Such a finding is of significance, especially in developing countries in South-East Asia and South America where bamboo is predominantly grown.

Table 2 Summary of test results for natural Dendrocalamus Asper poles tested under four-point bending (Shrestha and Crews 2014)

Sample	MoR MPa	MoE GPa
A1	42.3	18.2
A2	74.5	21.7
A3	85.1	20.1
A4	66.2	17.6
A5	65.6	19.2
A7	111.7	20.7
A8	98.6	20.8
A9	56.3	18.0
A10	40.8	9.5
Mean	71.2	18.4
CoV	34%	20%

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